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(19)

(54) OPTICAL APPARATUS

(71) We, THE RANK ORGANISATION LIMITED, of Millbank Tower, Millbank, London, S.W.1., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a liquid crystal optical display device. More particularly, the invention concerns optical display devices employing twisted nematic "field effect" liquid crystal displays.

A field effect twisted nematic liquid crystal display comprises a thin layer of nematic liquid crystal contained in a cell between two plane parallel electrode surfaces. In the homogeneous condition, in the absence of an applied electric field, the nematic liquid crystal molecules align themselves parallel to the electrode surfaces, in directions which are aligned with respective linear surface features on the two electrode surfaces, produced, for example by rubbing the surfaces or by directional evaporation of coatings on the surfaces. The two directions of alignment of the liquid crystal molecules at the two electrode surfaces are usually arranged to be at right angles to each other, and in this condition the nematic liquid crystal in the homogeneous state has a twisted structure between the electrode surfaces, exhibiting optical activity such that plane polarized light entering the cell through one electrode surfaces has its plane of polarization rotated through 90° in passing through the liquid crystal.

The twisted nematic liquid crystal display makes use of the well known phenomenon whereby the application of an electric field to a liquid crystal cell as described above in a direction perpendicular to the electrode surfaces, by applying a potential difference between the electrode surfaces above a threshold voltage, causes the liquid crystal to adopt a "homeotropic" structure, supplanting the twisted structure of the homogeneous state, in which the previously mentioned 90° rotation of the plane of polarized light does not occur. By providing a suitably orientated analyser and directing plane-polarized light through the cell it is possible to provide a visual distinction between those areas of the cell in which the liquid crystal is in the hemeotropic condition, to which an electric field is applied, and those areas which are in the homogeneous and twisted condition, without an applied field. A switchable visual display of any desired pattern can be provided by selectively applying the requisite voltage to appropriately shaped electrode surfaces.

A problem associated with liquid crystal optical display devices of the above mentioned type is that the viewing angle of the display is limited. This limitation is due chiefly to the fact that the homeotropic liquid crystal behaves in effect like a uniaxial crystal, with its optic axis perpendicular or nearly perpendicular to the electrode surfaces of the cell. When a uniaxial crystal is viewed (in uncollimated light) in a direction roughly parallel to its optic axis through appropriately orientated polarizers the resulting field of view consists basically of a cross with its arms orientated parallel to the polarizing axes of the polarizers, and in a liquid crystal display device, the thicker the liquid crystal layer, the greater its optical anisotropy, and the thinner the arms of the cross, so that as a result the angle subtended by the central region of the cross is smaller. By contrast, homogeneous regions in a liquid crystal display cell, that is, the un-energised areas, have a wide viewing angle, since there is no effective uniaxial layer in these regions.

This disparity between the viewing angles of the energised and unenergised regions of a field effect liquid crystal display device is undesirable, particularly in a display device of the black on white type.

The viewing angle of field effect liquid crystal displays can, of course, be increased by making the liquid crystal layer as thin as

possible, but there are practical limits to the thickness of the liquid crystal layer.

The present invention provides a solution to this problem by the inclusion in a liquid crystal display device as aforesaid of a uniaxial compensating layer having an optical anisotropy of opposite sign to that of the liquid crystal layer when in its hemeotropic state.

Accordingly, the present invention provides a liquid crystal optical display device comprising a cell having plane parallel electrode surfaces between which a nematic liquid crystal is contained, the electrode surfaces having differently directed linear surface features such that, in the un-energised state, the liquid crystal is in a homogeneous orientation with its adjacent molecules aligned with the surface features of the respective electrode surfaces so that the liquid crystal adopts a twisted structure between said electrode surfaces, exhibiting optical activity, the homogeneous orientation being supplanted by a homeotropic orientation when a potential difference exceeding a predetermined threshold is applied between the electrode surfaces, the liquid crystal in said hemoetropic orientation exhibiting uniaxial anisotropy with its optic axis substantially perpendicular to the electrode surfaces, and a uniaxial compensating layer disposed adjacent and parallel to the cell and having an optic axis parallel to that of the hemeotropic liquid crystal and with an optical anisotropy of opposite sign to that of the latter, so that the viewing angle of the central illuminated area of the device when plane polarised light is transmitted through the cell and the said layer is in the hemoetropic condition of the liquid crystal is increased.

Preferably the cell is interposed between two polarizers arranged with their polarising axes substantially parallel to the linear surface features of the respective electrode surfaces.

The linear surface features on the two electrode surfaces are preferably perpendicular to each other.

The uniaxial compensating layer is preferably so constituted and arranged that the viewing angles of the device in the homogeneous and homeotropic states of the liquid crystal are substantially equal.

The effect of the uniaxial compensating layer can be understood with reference to the "ordinary" and "extraordinary" rays transmitted through the uniaxial compensating layer. The cruciform pattern observed when the light transmitted through this layer is viewed through a suitably orientated analyser has a central area where the ordinary and extraordinary rays pass through the uniaxial layer and emerge in substantially the same optical phase relative to each other i.e. transmission parallel to the optic axis: those regions outside the cross correspond to areas where the relative optical phases of the ordinary and extraordinary rays differ i.e. transmission to the viewer by a path which is somewhat inclined to the optic axis — that is, their optical path lengths through the layer are different.

By inserting the compensating layer of optical anisotropy of opposite sign to that of the liquid crystal in the homeotropic state a further shift in the optical phases of the ordinary and extraordinary rays is produced, and this shift is moreover in the opposite sense to that caused by the liquid crystal layer. Consequently the two rays emerge from the device with their relative optical phases better matched than they would be in the absence of the compensating layer.

It would be appreciated that the addition of the compensating uniaxial layer necessarily leads to a decrease in the viewing angle of the homogeneous or un-energised areas of the liquid crystal cell, since the light passing through these areas now traverses the uniaxial compensating layer, whereas in the absence of this layer no uniaxial material would lie in the path of this light. Thus the improvement brought about by the present invention may be regarded as an enhancement of the viewing angle of the energised areas of the field effect display device, at the expense of the viewing angle of the un-energised areas of the device.

It is possible, by appropriate selection of the thickness of the uniaxial compensating layer for example, to achieve a compromise whereby the viewing angles of the energised and un-energised areas of the liquid crystal cell are substantially equal, maximising the viewing angle over which the display as a whole is acceptable, particularly in the case of a black on white display.

WHAT WE CLAIM IS:—

1. A liquid crystal optical display device comprising a cell having plane parallel electrode surfaces between which a nematic liquid crystal is contained, the electrode surfaces having differently directed linear surface features such that, in the un-energised state the liquid crystal is in a homogeneous orientation with its adjacent molecules aligned with the surface features of the respective electrode surfaces so that the liquid crystal adopts a twisted structure between said electrode surfaces, exhibiting optical activity, the homogeneous orientation being supplanted by a homeotropic orientation when a potential difference exceeding a

predetermined threshold is applied between the electrode surfaces, the liquid crystal in said homeotropic orientation exhibiting uniaxial optical anisotropy with its optic axis substantially perpendicular to the electrode surfaces, and a uniaxial compensating layer disposed adjacent and parallel to the cell and having an optic axis parallel to that of the homeotropic liquid crystal and with an optical anisotropy of opposite sign to that of the latter, so that the viewing angle of the central illuminated area of the device when plane polarised light is transmitted through the cell and the said layer in the homeotropic condition of the liquid crystal is increased.

2. A display device according to Claim 1, in which the cell is interposed between two polarisers arranged with their polarising axes substantially parallel to the linear surface features of the respective electrode surfaces.

3. A display device according to Claim 1 or Claim 2, in which the linear surface features on the two electrode surfaces are perpendicular to each other.

4. A display device according to any one of Claims 1 to 3, in which the uniaxial compensating layer is so constituted and arranged that the viewing angles of the device is homogeneous and homeotropic states of the liquid crystal are substantially equal.

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